Treatment of High Strength Vegetable Processing Wastewater with a Sequencing Batch Reactor

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Abstract— **The feasibility of an aerobic sequencing batch reactor was studied at the lab scale to treat the high organic loading present in two vegetable processing wastewaters. Hydraulic retention time (HRT) was varied to evaluate its effect on the removal efficiency of chemical oxygen demand (COD), total Kjeldahl nitrogen (TKN) and total phosphorus (TP). The results showed that a longer HRT promoted the removal of TP, while the liquid drawn per cycle had a larger effect on the COD removal efficiency. An increase in the COD/TKN and TKN/TP ratio decreased the removal efficiency of TKN and TP respectively. The optimized configuration was able to reduce the wastewater loadings to acceptable sewer discharge limits, making it possible eliminate the sewer surcharge fees.**

Keywords — aerobic sequencing batch reactor, vegetable wastewater, chemical oxygen demand, nutrients

I. Introduction

Food processors in many jurisdictions, including Ontario, experience high sewer disposal fees that include surcharge rates due to the elevated levels of organic loading and nutrients in the plant wastewater. A prime example is the fruit and vegetable industry, where large quantities of water are used to clean and process the fruits and vegetables. The result is wastewater that contains high amounts of organic residues and nutrients. The parameters affected the most are biological oxygen demand (BOD_5), suspended solids (SS) and TKN and TP levels. The high levels measured for BOD_5 and TSS, along with the negative effects from nitrogen and phosphorus through eutrophication, require treatment of the wastewater before it can be discharged into surface water bodies [1]. Therefore, many municipalities impose a surcharge fee on food and vegetable processors for the wastewater that is discharged to the sewer system. These extra fees help recover the additional costs incurred for treating the high organic loading and nutrients contained in the processing plant wastewater. As a result, many food processors want treatment systems that reduce the loading levels in the plant effluent.

Limitations for sanitary sewer discharges are set by the municipalities. Review of the limits in the region show they are quite similar, with BOD at 300 mg/L, TSS at 350 mg/L, TKN at 100 mg/L, TP at 10 mg/L and pH greater than 6 and less than 11.5 [2, 3]. For the City of Toronto, the surcharge is based on the greater of exceeding concentrations of BOD_5 or total suspended solids (TSS) at a rate of \$0.57/kg [2]. For the City of Mississauga, which is governed under the Region of Peel, the surcharge would be \$328/1000 m^3 for BOD_5, TSS and TP [4]. The surcharge fee is dependent on the concentration of the effluent wastewater discharged by the processor and the quantity of wastewater discharged to the sanitary sewers. To reduce the surcharge fee, either the concentration of the parameter or the quantity of water being discharged needs to be reduced.

Many different technologies are available to reduce the concentrations of BOD_5, TKN and TP. Some of these technologies include membrane bioreactor, sequencing batch reactor, dissolved air flotation system, and lagoons, just to name a few. However, limited information is available on technology suitable for all types of food processing wastewater, especially with high strength BOD_5 and nutrient loadings [5], as fruit and vegetable processing wastewater has not been an area of concern. This is despite the tremendous amount of research that has already been conducted on the removal of nutrients and organic loading from different types of wastewater, such as municipal, dairy or meat processing.

Therefore, research was completed to determine the possibility of using a sequencing batch reactor (SBR) to reduce the organic loading (BOD) and nutrient removal (TN and TP) to a level below the allowable sanitary sewer discharge limit. Attaining this level for vegetable

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processing wastewater would eliminate sewer discharge surcharges. The sequencing batch reactor was selected for its simple operation and small footprint [6].

A sequencing batch reactor (SBR) has 5 process steps, which are, feed, react, settle, decant and idle [7, 8, 9]. Feed allows wastewater to enter into the system. React allows for either aeration or mixing to occur. Settle allows for the sludge within the bioreactor to settle out to the bottom. The decant stage allows for water at the top of the reactor to be pumped out from the system. Finally, the idle stage is the wait period between when the next cycle would occur. Since the aim of the research was BOD_5, TKN and TP removal, the react phase was broken down into an anaerobic and aerobic phase. TSS removal was also monitored as it is a parameter of interest from a sewer discharge perspective, but with vegetable TSS being relatively easy to remove during the settling phase, no special efforts were made to improve removal of TSS.

Table I outlines the versatility of the SBR and its capability to remove organic loading and nutrients from various types of wastewater. Further, it outlines some of the major parameters that were monitored in the various studies.

TABLE I. VARIOUS TYPES OF WASTEWATER TREATED WITH SBR

Wastewater	**Initial Values (mg/L)**			**HRT**	**Removal Efficiency (%)**			**Ref.**
	COD	***TKN***	***TP***	**(h)**	***COD***	***TKN***	***TP***	
Piggery	10580	1258	236	240	93	90	95	[12]
Shrimp	1555	146	N/A	N/A	82	100	N/A	[7]
Domestic	296	30	7	16	95	97	80	[13]
Dairy	10000	780	N/A	24	80	75	N/A	[14]
Brewery	2853	200	N/A	25.4	97	N/A	N/A	[8]
Landfill and Dairy	7250	75	N/A	240	99	80	N/A	[15]
Slaughter	1440	186	15	48	94	74	40	[16]
Piggery	2255	909	89	24	64	100	98	[17]
Malting	912	11	39	32	66	59	N/A	[18]

Based on the findings outlined in Table I and for the purposes of this research, the hydraulic retention time (HRT) was chosen as the varying parameter, as it is one of the simplest parameters to alter and yet has a significant impact on treatment efficiency. Furthermore, research was needed on HRT as limited relationships were found between HRT and COD removal efficiency for vegetable processing wastewater as shown by Table I. Additionally, review of Table I shows that data for vegetable processing wastewater by an aerobic SBR is lacking, showing the novelty of this study.

For many municipalities, surcharge fees are not being charged when nitrogen and phosphorus exceed the respective municipal sanitary sewer limits. However, due to increased environmental concerns, various municipalities have noted that there are plans to include nutrients in the surcharge calculations. The City of Toronto is one of the municipalities who recently changed their policy and are now charging for excess discharge of total Kjeldahl nitrogen and total phosphorous [10]. Accordingly, the research into the SBR was developed to also address nutrient removal. Typically a SBR for nitrogen removal only uses the nitrification-denitrification process, in which the system is aerated for a certain amount of time and then is allowed to mix. The nitrification process allows for the ammonia within the system to be converted to nitrate. The denitrification process allows for the nitrate to be converted to nitrogen gas that is subsequently released into the atmosphere, the desired outcome. However, with phosphorus removal also being important, an anaerobic step was added to the process cycle. Thereby, the operation of the SBR was anaerobic, aerobic and finally anoxic.

Therefore, the overall goals for this research were to reduce the concentration of organic loading (BOD) and nutrients (TKN and TP) to levels below the allowable municipal wastewater discharge limit, which would avoid current (2014) sewer surcharge costs. However, the ultimate goal would be to check if vegetable processing wastewater could be treated to a level below the storm sewer discharge limit, so that the wastewater could be directly discharged into a local waterbody or even possibly reused on-site.

The vegetable processing wastewaters used to test the bench scale SBR were collected from two industrial partners. These facilities process multiple types of vegetables such as carrots, beets, potatoes and lettuce. The operation includes, shredding, washing and cutting. The wastewater from Industrial Partner 1 (IP1) was used to develop the testing protocols and determine ideal operational conditions, which included the duration of aeration and the volume of liquid removed per cycle from the SBR. These ideal operation conditions were then tested with the wastewater from Industrial Partner 2 (IP2) to check for transferability of results as past experiences have shown that process performance changes from wastewater to wastewater as characteristics of the sludge also change [11].

From competitive reasons, the industrial partners did not want to disclose the type of vegetables that they processed on a daily basis. However, for IP1, the wastewater discharge rate was 200 m^3 a day with a production rate of 17.5 hours a day, in operation for 6 days a week. The remaining time allows for cleaning and sanitation [19]. IP2 discharged at an average rate of 140 m^3 a day of wastewater with 16 hour per day operation for 6 days a week. The remaining shift was used to clean the machinery and sanitation.

II. METHOD

A. Process and SBR Setup

The SBR reactor (Fig. 1) had a volume of 5 L and was made from plexi-glass with a mixer in the bottom from Cole-Parmer, model RK-50705-00. The aeration pump came from Septic Solutions, model HP-60 and the air stone was from Alita Industries, model ASD-100C. A Masterflex pump, model RK-07528-30 with head attachment model SI-07518-00 used to decant the system as the influent and effluent pump.

Return activated sludge was collected from the City of Guelph Municipal Wastewater Treatment Plant to seed the SBR. Approximately 2 L of return sludge was poured into the 5 L reactor, which was topped off with vegetable processing wastewater from the industrial partner being studied. The system was allowed to acclimate for 2 months before testing was started. Acclimation consisted of feeding the reactor with fresh vegetable processing wastewater at 9 AM, followed by a 2 h mixing period, an aeration period of 5 hours and finally a settling period of 30 minutes. Since the reactor was a batch reactor, 1.5 L of effluent was removed from the system after the settling period. The effluent removed and the aeration time was then subsequently used to determine the HRT, where the HRT was calculated as the cycle time divided by the ratio of decanted effluent drawn. As such, the HRT was 26.67 h during acclimation. For SRT, 100 mL of sludge was removed daily, which equates to a SRT of 50 d.

The SBR was allowed to run one cycle per day. After the cycle was completed, 5 h of settling occurred, followed by 5 h of aeration throughout the night. The system was then allowed to settle again before the next day. Temperature in the lab was allowed to fluctuate with the thermostat which was set to 20°C, where the fluctuation should not have been greater than ±2°C. The aerator pumped 300 L/h of air into the system which produced a dissolved oxygen concentration well above the minimum requirement of 3 mg/L [20].

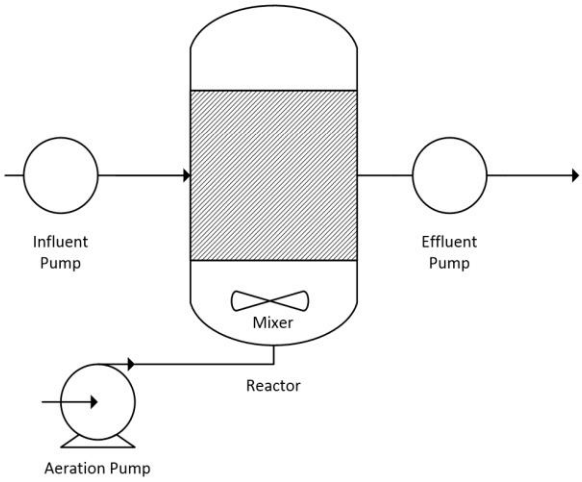

Figure 1. Schematic Diagram of Aerobic SBR Setup Used

Testing for COD, TKN and TP was done with the Hach testing kits and a DR 5000 Spectrophotometer. Hach testing kits used for COD, TKN and TP testing were TNT822, TNT880 and TNT845 respectively.

The COD test was used in place of BOD_5 because COD was a faster test, with COD being an indicator that measures both the organic and inorganic matter in water. The BOD_5 only reports the amount of organic matter in water. Thus the amount of COD will be greater than BOD_5, leading to the BOD_5/COD ratio which can be used to estimate BOD_5 values [21]. Since the BOD_5/COD values are wastewater specific, comparison tests were completed to determine the BOD_5/COD ratio for the vegetable wastewater being studied. BOD_5 testing was done according to Standard Methods [22]. For IP1, it was determined that the BOD_5/COD ratio was 0.44, while for IP2 it was 0.62. Ranges in the literature include 0.1 for carrot [23], 0.56 for piggery [24] and 0.46 for agricultural waste [25].

Total suspended solids were analyzed according to Section 2540 of APHA-AWWA-WPCF [26].

Standard solutions for COD, TKN and TP were purchased and used for calibration. It was determined that the percent difference was less than 2% for both COD and TP. The percent difference for TKN ranged from 2% to 7.5%, depending on the dilution used, which was considered acceptable based on communication with Hach. Hach stated that a 10% percent difference from the expected value was acceptable [27].

B. Vegetable Processing Wastewater

Vegetable processing wastewater was collected weekly from IP1, for which the system was developed and refined. IP1 processed multiple types of vegetables throughout the year. The facility consistently produced shredded iceberg lettuce and was also capable of handling peeled potatoes and cassava, shredded carrots and processed beets to name a few. The mean concentrations for the effluent from IP1 were COD at 1826 mg/L ± 523 (n= 70) mg/L, TKN at 16.7 mg/L ±14 (n = 42) and TP 9.5 mg/L ± 5.5 (n=37).

Wastewater from IP2 was collected near the end of the study to determine if the SBR system configuration could be transferred to the second processor. IP2 processes a variety of root vegetables, but also processes apples for select clients. The mean concentrations for the effluent from IP2 were COD at 934 mg/L ± 130 (n= 10) mg/L, TKN at 53.6 mg/L ± 37 (n = 10) and TP 7.5 mg/L ± 4.6 (n=10).

Representative wastewater samples were collected from both industrial partners prior to discharge into the sewer system and stored in a 20 L carboy in a refrigerator at 4°C until needed as feed. With the wastewater collected prior to the municipal sewer system, it was not deemed to be biohazardous. Wastewater was used in the reactor directly without dilution.

C. Operations

The operation of the SBR involved 5 phases: fill, anaerobic, aerobic, settle, decant and idle. The settle phase suffices for the anoxic phase. Fill, anaerobic, settle, decant and idle were all allocated 15 min, 2 h, 30 min, 15 min and 30 min respectively. The anaerobic phase was allocated 2 h based on Kargi and Uygur [28]. Further, the SRT was kept constant at 50 d throughout the duration of the experiments. All the experiments were carried out manually and were not operated by any computer control.

Two sets of experiments were conducted. The first set of experiments were used to observe the change of removal efficiency with the change in aeration time and the second set of experiments will observe the change in liquid drawn from the system per cycle. Each experiment was carried out for 3 weeks, the first week allowed for acclimation, while the following two weeks allowed for experimentation. Samples were taken 3 times a week to create replicates for each experiment. Table II outlines the set of experiments completed for IP1 and the overall conditions for Experiments 1 through 6. The amount of liquid drawn from the 5 L system was pre-defined at 1.5 L for the first 3 experiments, while the other 3 experiments had varying amounts of effluent withdrawn. The condition which gave the optimal results was then applied to Experiments 4 through 6.

Overall, the reactor was allowed to acclimate for 60 d before beginning the optimization experimentation. The biomass drawn from the system was kept constant at 100 mL and the aeration time was kept constant at 5 h.

The experiments completed on IP2 were based on the ideal conditions identified for IP1. The only condition changed was the source of the wastewater.

III. RESULTS AND DISCUSSION

A. Acclimation

An acclimation period was used to ensure that the microbial population was acclimated to the food processing wastewater being tested.

TABLE II. EXPERIMENTAL CONDITIONS AND CYCLES FOR IP1

Exp	Day	Cycle Time (h)	Aeration Time (min)	Liquid Drawn (L)	Ratio	HRT (h)
1	111 to 121	12	450	1.5	0.3	40
2	133 to 142	8	270	1.5	0.3	26.7
3	189 to 196	6	150	1.5	0.3	20
4	217 to 226	6	150	1	0.2	30
5	238 to 247	6	150	2	0.4	15
6	259 to 266	6	150	2.5	0.5	12

This was important when evaluating ideal operational conditions for a new treatment process. For the acclimation period, the desired standard deviation for the COD results during the acclimation period was less than 10%. A 10% standard deviation limit gave reassurance that the data obtained were consistent, which allowed for the experiments to proceed, and gave confidence that the trends observed were real.

Review of the removal efficiency data during the acclimation period showed that data obtained from Day 1 to Day 62 produced a standard deviation of 13.5%, which was higher than the desired 10%. However, a large deviation in the influent COD levels occurred during Day 54 to 62, with a significant jump on Day 57, which was consistent with a variable processing schedule. Accordingly, Day 57 was considered an outlier. Removing this outlier reduced the overall standard deviation to 8.4%, which was within the desired 10% standard deviation mark. In retrospect, the actual experimentation phase could have started earlier, since the results obtained showed a deviation of less than 10% during the earlier stages of experimentation.

B. Treatment Results for IP1

The goal of this research was to determine the possibility of utilizing a sequencing batch reactor for the treatment of organic loading and the removal of nutrients to eliminate sewer discharge surcharge fees.

Table II outlines the date and condition run for each experiment to identify the optimum operational conditions to meet this condition, while Table III outlines the average concentration and standard deviation of the data. Each experiment lasted approximately 3 weeks, in which 1 week was used for acclimation for the new condition. The other 2 weeks were used for data collection. The data was typically collected on Monday, Wednesday and Friday of the week and at least 4 points per experiment were collected.

TABLE III. AVERAGES AND STANDARD DEVIATIONS FOR IP1

Exp.	COD (mg/L)		TKN (mg/L)		TP (mg/L)	
	Avg.	*SD*	*Avg.*	*SD*	*Avg.*	*SD*
1	0.95	0.01	0.8	0.05	0.7	0.24
2	0.96	0.01	0.9	0.04	0.47	0.1
3	0.96	0.01	0.89	0.03	0.47	0.18
4	0.95	0	0.79	0.09	0.74	0.11
5	0.29	0.17	0.63	0.07	N/A	N/A
6	0.39	0.13	0.74	0.08	0.49	0.17

Table III contains the average removal and standard deviations for COD, TKN and TP. The standard deviation for COD for Experiments 1 through 4 was on the scale of 1% or less. The standard deviations for TKN and TP for Experiment 1 through 4 ranged between 3% to 9% and 10% to 24% respectively. As such, TP was the hardest parameter to control, which is consistent for the biological removal of phosphorous.

Phosphorous removal was dependent on the anaerobic and aerobic periods. During the anaerobic period, ortho-phosphate was released back into the liquid. During the aerobic period, the microorganisms would uptake the previously released ortho-phosphate, thus, giving an overall excess removal. The lack of phosphorus uptake during the aerobic period could have been the result of the microorganisms using residual nitrite/nitrate as the energy source instead of the phosphate.

TABLE IV. REMOVAL EFFICIENCY OF IP1

Condition in Terms of HRT (h)		COD (%)	TKN (%)	TP (%)
Aeration Time	***40***	97	88	47
	26.7	96	90	47
	20	94	80	70
	30	95	78	73
Volume of Wastewater Removed per Cycle	***20***	97	88	48
	15	29	62	N/A
	12	38	74	49

Table IV shows that the highest removal efficiencies for COD and TKN were achieved when the HRT exceeded 20 h. Beyond a HRT of 20 h, the removal efficiency for COD was consistent at around 95%, with minor fluctuations. However, when the HRT value dropped below 20 h, the removal efficiency of COD appears to be extremely minimal and even reducing to 29% at 15 h. The lack of removal efficiency below 20 h was most likely due to the lack of reaction time. These COD results reflect the inability of meeting the current municipal guidelines of 300 mg/L for BOD_5 or 680 mg/L as COD for Experiment 5 and 6. Thus, there could have been a threshold for a minimum required amount of reaction time, where if the reaction time was less than the threshold, minimal removal efficiency was achieved.

Similar conclusions were drawn from the TKN results. When HRT exceeds 20 h, there was minimal gain in the removal efficiency of TKN. However, it appears that there was a peak in the removal efficiency with an HRT between 20 and 26.7 h. An HRT of 15 h produced TKN removal of 63.3%. Whereas, at 20 h, the removal efficiency was at 86.6%. Again, this could have been the result of a lack of reaction time for the microorganisms. Furthermore, at 30 h the removal efficiency of TKN actually decreased but TP removal increased. This could have indicated that there was an exchange where the nitrifying microorganisms dominated up to a certain point in time.

The trend for the removal of TP was also similar to that of both COD and TKN, where the TP removal efficiency was reduced when the HRT was at 15 h. However, unlike both COD and TKN, the highest TP removal comes from a HRT much longer than 26.7 h. The change in TP was consistent amongst the 12 h, 20 h and 26.7 h. However, at 30 h, the removal efficiency increased to 74.5 %. Chiou et al. [29] reported that an anaerobic/aerobic time ratio at 1:2 provided the highest phosphorous removal. The 30 h of HRT would equate to 2.5 h of aeration and 2 h of anaerobic, which would equate to a ratio of 0.8. Amongst the experiments with an HRT of 6 h, the one that yielded the highest removal results was the one with the lowest volume of wastewater removed per cycle. This proved again that the liquid drawn from the system had a greater effect on the removal efficiency.

The reduction of TKN and increase in TP removal would mean that there was a balance between the removal of the two. If the SBR was to be implemented on site, then further research will be required to ensure that the sanitary sewer discharge limit for COD, TKN and TP will be met on a daily basis. The facility may be required to implement a modified treatment system to ensure that enough nutrients are available for the microorganisms.

C. Effect of Aeration

Table IV outlines the effect of aeration on removal efficiency. It appears that aeration has little effect on the removal efficiency for COD. A paired t-test was used to determine that there was no significant difference between the COD removal and the effects of aeration. Furthermore, there was no statistical difference between the HRT of 20 h versus 26.7 h in COD removal. However, there was a statistical difference in TKN removal with the 40 h and 26.7 h HRT when compared to the HRT of 20 h. Similar differences were noted for TP. A possible reason for the high phosphorus removal at a HRT of 20 h was the presence of sufficient biomass, providing good uptake.

Fongsatitkul et al. [30] reported that with constant influent concentrations for COD, TKN and TP, the removal efficiency of TKN and TP were affected the most when the operation time was changed. COD removal was nearly identical to the other conditions but TKN and TP removals decreased by 16.8% and 31.5% respectively. Conversely, Kargi and Uygur [28] showed that the effect of aeration had little effect on the overall removal efficiency of COD. Contrary to current research, trends suggest that increasing aeration times resulted in a higher ammonia-nitrogen removal and a diminishing TP removal when the HRT increased from 20 h to 26.7.

D. Effect of Liquid Exchange

A closer look at the experimental results for Experiment 3 through 6 given in Table IV shows the effects of liquid drawn from the system per cycle and the corresponding affect on hydraulic retention time. These 4 experiments had the same amount of aeration time but had different volumes of liquid drawn from the system during each cycle. The drastic changes in the COD removal was connected to the reduced HRT within the system. The removal of COD relies more heavily on the HRT via the liquid drawn from the system as compared to the time of aeration. For TKN removal, as a function of wastewater removed, the best removal occurs as the HRT increases. Table IV shows that this was the same trend for TP removal, with the longest HRT of 30 h providing the best removal. Based on the completed work, the recommended HRT for IP1 was 30 hours with 2.5 hours of aeration and 1 L of liquid drawn from the system per cycle.

E. Effect of Influent COD/TKN on TKN Removal

Review of influent COD/TKN ratio on TKN removal efficiency, showed that three experiments yielded the highest coefficient of determination: Experiment 1, Experiment 3 and Experiment 4. The results of these three experiments were plotted in Fig. 2 to show the effect of COD/TKN ratio on TKN removal efficiency. Fig. 2 shows that there was a general decrease in removal efficiency with a corresponding increase in COD/TKN ratio as shown by the regression curves of the 3 experiments (all having reasonable correlation coefficients). The decrease in removal efficiency could be the result of an imbalance between the COD and TKN. Typically the desired COD/TKN ratio should be at a value of 10 [31, 32] as opposed to the current COD/TKN ratio of over 100. Brucculeri et al. [33] determined that when the COD/TKN rate increased from 7 to 26, the COD removed by biomass declined from 27% to 22%. Thus, there are diminishing returns for an increasing COD/TKN ratio. For comparison, Mees et al. [34] found that a cycle time of 8 h and a C/N ratio of 3 to 6 produced removal efficiencies of over 80% for nitrite and nitrate-nitrogen removal with poultry slaughterhouse wastewater.

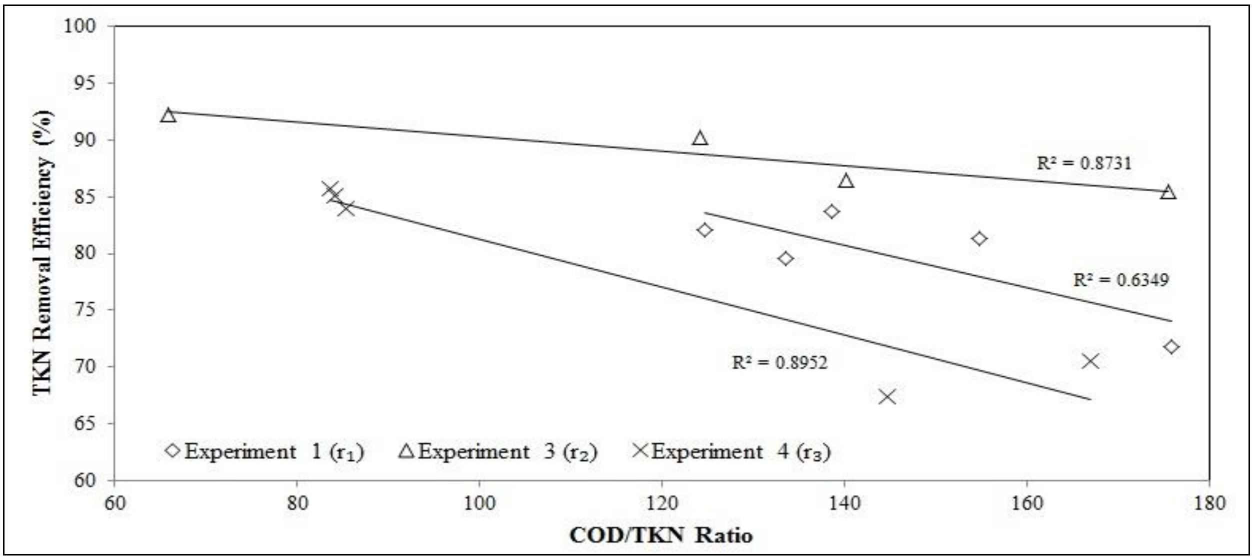

Figure 2. Influent COD/TKN Ratio and its Effect on TKN Removal

F. *Effect of Influent TKN/TP on TP Removal*

Similar to COD/TKN, the experiments with the highest coefficient of determination were selected and plotted in Fig. 3. By determining the most effective TKN/TP ratio, an operations engineer could adjust the amount of nitrogen or phosphorous in the system on a daily or weekly basis to optimize for nutrient removal. Experiment 1 produced a positive correlation with an increase in TKN/TP ratio that would produce increasing TP removal efficiency. However, Experiment 6 produced a negative correlation when there was an increase in TKN/TP ratio. Experiment 3 had TKN/TP points which overlapped both Experiments 1 and 6. From Fig. 3 it was concluded that there was an increase in TP removal with an increase in TKN/TP ratio until a maximum ratio of about 2.5 was reached. Beyond this point, there would be a negative TP removal efficiency with increasing TKN/TP ratio. More research is needed to confirm the findings of Fig. 3. However, Fongsatitikul et al. [35] reported that a high influent COD concentration reduced the removal efficiencies of both TKN and TP when the influent concentrations of both TKN and TP were kept constant. This was consistent with the findings within the completed study, since it was also found that a high COD/TKN ratio produced declining TKN removal efficiency results.

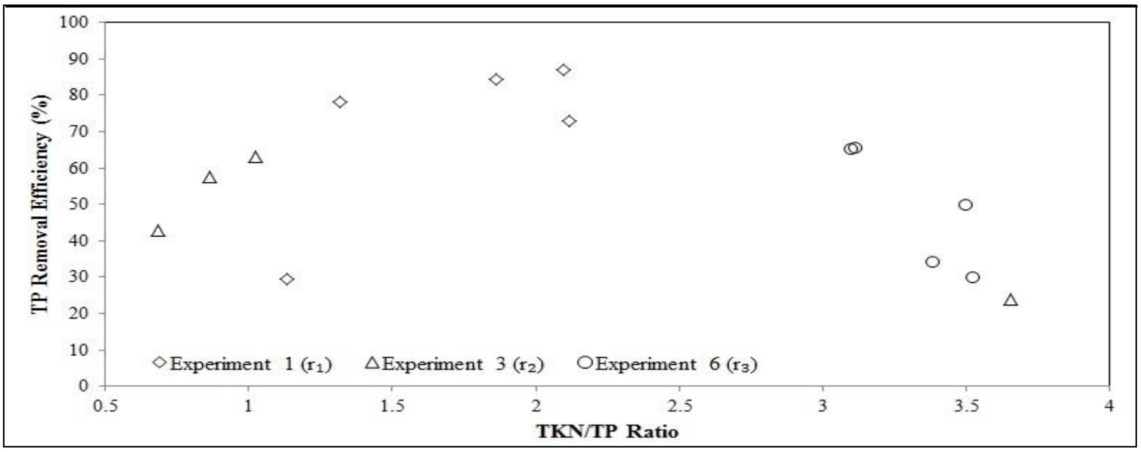

Figure 3. Influent TKN/TP Ratio and its Effect on TP Removal

G. *Industrial Partner 2*

Wastewater from IP2 was tested to confirm the system configuration results obtained from IP1. As expected, the treatment results were poor, with COD, TKN and TP removal 70%, 15% and 20% respectively, with final average effluent values at 631 mg/L, 53.4 mg/L and 7.5 mg/L respectively. This confirms the need for systems to be designed for site specific conditions, similar to municipal wastewater treatment plants

IV. CONCLUSIONS

The research showed the feasibility of using the SBR to reduce BOD and TSS concentrations to values well below the sewer discharge limits, saving the food processor sewer surcharge costs. COD removal was dependant on the amount of liquid drawn from the reactor, rather than the aeration time, while a longer HRT ensured a greater TP removal. A lower HRT would enable more wastewater to be processed without the sacrifice of efficiency. For the nutrient levels, the removal was encouraging, but further optimization is required to ensure that the discharge limits are consistently met.

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